Duplicity and Evolution Status of the Early-Type Be Star V622 Per, the Member of the χ Per Open Star Cluster

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Radial velocities analysis based on high-resolution spectra, obtained in the Hα region and low resolution spectra obtained in the region 4420-4960Å together with radial velocities, taken from other published sources allow us to calculate orbital parameters of the massive binary system V622 Per. It is shown that the system has an orbital period 5.214(29) days, T_0 = 2450661(4) and is a post mass transfer binary. From light curve analysis of the ellipsoidal variability we obtained inclination angle of the system and temperature of the components. Luminosity ration of the components was found of about 4:1. T_{eff} and $log\,g$ were estimated for each component. It is shown that primary, less massive but more bright star, is an evolved object that has lost large part of its mass during the evolution. Estimations of chemical composition of the primary show noticeable enrichment by products of the CNO cycles. E.g. He/H reaches 0.18, nitrogen is in excess of about 0.5 dex, carbon has low abundances (by 2-3 dex lower) and oxygen has 1 dex lower than solar abundance. The possible evolution of the binary with the known age 14 Myrs is discussed.

Introduction

Theory of the stellar evolution provides a description of the interior structure and the observable properties of a star given initial mass and chemical composition as a function of age. Significant progress has been made during recent years in understanding the physical processes that govern the structure and evolution of stars. Evolutional models are improving and the main direction of modeling is to account for evolution parameters of conservation system on the one hand and exchange by angular momentum on the other hand.

The close binaries are powerful tools for testing stellar structure and evolution models, since the fundamental properties of the components (masses, radii, luminosities, etc.) can be accurately determined from the observations. These systems in young open clusters provide a way of finding the age, distance, accurate masses, radii and chemical composition, making a good discriminating test of the physical ingredients of theoretical models. Presences of massive interacting binaries in open stellar clusters is the useful tools for understanding of short-lived phases of their evolution. Such stars are rare and each of them requires detail analysis.

During the studying of the hot B stars in young open clusters h/χ Per we found and analyzed binary system V622 Per. The star may be a good indicator to verify the theories of evolution. Early spectral type of the star B2III [11], relatively short orbital period $\sim 5.2^d$ [10], presence of emission details in the spectrum and unusual chemical composition of the atmosphere [13] mean that the star is an interacting binary with unknown evolutional status, but located in the open stellar cluster χ Per of the known age.

From available data as well as those given in literature we have calculated orbit, period, temperature, gravity, rotational velocities. We also have estimated chemical composition of the components.

Observations and data reduction

The spectroscopic observations of V622 Per were carried out over four years from 1997 to 2000 as a part of studying emission spectrum of the Be stars in the young double open cluster h and χ Per (NGC 869 and NGC 884). We used the Coudé focus of the 2.6-m telescope of the Crimean Astrophysical Observatory. The spectral resolution was about 30000. The signal-to-noise ratio was $\sim$100. A total of 8 spectra were obtained in the Hα line region and one in the region of the HeI $\lambda\,6678\,$Å line.

Additionally, as a part of program of studying B and Be stars in the open stellar clusters, two medium 2.5 Å resolution spectra were obtained in the Nasmyth focus of the same telescope. They cover spectral region between 4420-4960 Å. The signal-to-noise ratio of these spectra was about 100.

Table 1: Orbital parameters of V622 Per based on radial velocity variability

Element	Orbital solution
P (days)	5.21429±0.00008
$T_{conj.1}$	2450661.4±0.2
K_1 (km s^{-1})	139±6
K_2 (km s^{-1})	99±11
q	1.40±0.13
e	0.05±0.04
ω°	236±36
γ_1 (km s^{-1})	-44±3
γ_2 (km s^{-1})	12±11
f_M (M$_{\odot}$)	1.46
$M_1 sin^3 i$ (M$_{\odot}$)	3.0
$M_2 sin^3 i$ (M$_{\odot}$)	4.3
$a_1 sin\, i$ ($R_{\odot}$)	14.3
$a_2 sin\, i$ ($R_{\odot}$)	10.2
No. of spectra	11 spectrograms and 3 velocities from [7, 8]

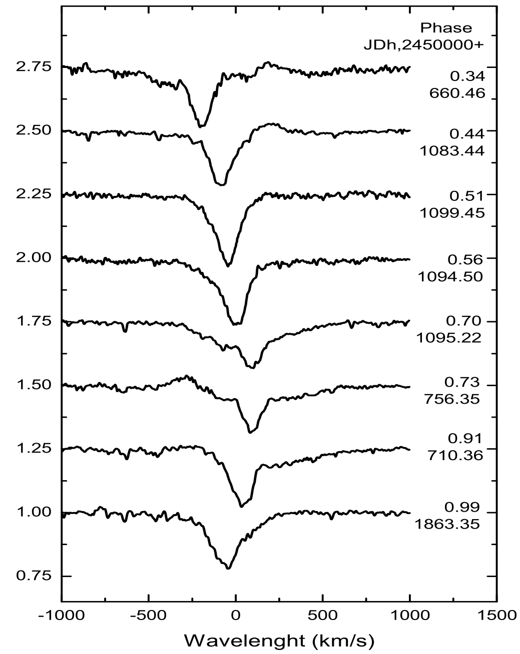

Figure 1: Hα line profiles of V622 Per. On the right side of each spectrum JD and phase of the orbital period is presented. Intensities of each next spectrum are shifted by 0.25.

Radial velocity (RV) and equivalent width (EW) of the eight Hα, one HeI λ 6678 Å and two medium resolution Nasmyth spectra were obtained. As it is seen from Fig.1, Hα line has complex profile and it is variable in the time domain. The most pronounced component is a sharp absorption line with large amplitude of RV variation. The signatures of the broad absorption component are also seen on the most part of our spectra. Additionally, some faint emission line is presented in the red or blue wings of the line, but some spectra have no noticeable emission or emission is hidden inside of the absorption profile.

The He I λ 6678 Å line profile can be seen in Fig.2. It has single-component line profile without noticeable emission and some faint signatures of the additional absorption component in the blue wing of the line.

The observed blue region of the spectra is presented in Fig.4. The Hβ line profile has no signs of emission component on the both of our spectra. The weak absorption from the secondary is seen in the blue wing of the line. As it seen from Fig.4, the red wing of the Hβ line has broad depression. It was found on all the spectra of other members of h/χ Per cluster, but absent in the spectra of the standard stars from the list in work [9]. It is associated with the interstellar absorption band with unknown identification [5] and it has a very broad, asymmetric feature. According to [5] the wings of the line extend shortward edge to at least 4870 Å and longward to 4909 Å. The deepest point is about 4882 Å.

Radial velocities analysis and orbital solution

According to the rich BV photometry from the paper [10], V622 Per is an ellipsoidal double system with the orbital period $P_{orb} = 5.2^d$. The large fraction of our RV measurements were obtained from the emission Hα line. Practically the same velocities of the He I and sharp component of the Hα lines, obtained in the same night, and "in phase" variability of the radial velocities, obtained from the Nasmyth spectra, allow us to conclude that sharp component of the Hα line mostly appears in the photosphere of the bright star and can be with some caution used in solving orbit of V622 Per. To confirm the value of orbital period derived in

[10] we used our RV measurements together with the data, obtained in [7, 8]. Periodogram analyses based on nonparametric statistics (Lafler-Kinman) were used for searching possible orbital period from radial velocities observations. Only one significant period, close to the value proposed in the work [10], was found.

In order to solve spectroscopic orbit we used the FOTEL code [4]. Obtained orbit solution is presented in the Table 1 and its graphical equivalent is present in Fig.3. As it is seen from orbital solution, V622 Per is an evolved massive system with the less massive, but more bright primary component. It has near circular orbit and low value of mass exchange.

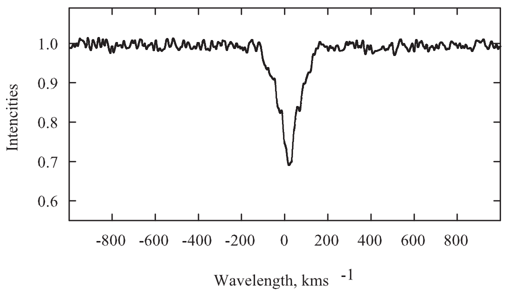

Figure 2: Line profile of the He I λ 6678 Å line, obtained at HJD = 2451094.577

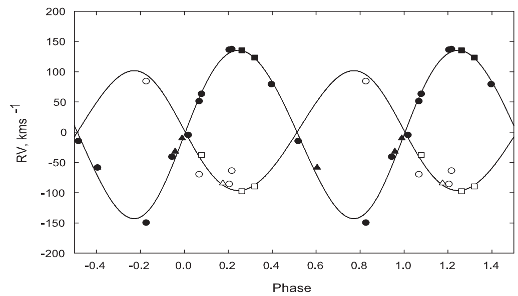

Figure 3: Radial velocity variability with the phase of orbital period. The filled symbols – orbital velocities of the primary component, open symbols – RVs of the secondary component. Filled circles – sharp component of the Hα and the He I λ 6678 Å lines. Circles – RVs derived from the Hα line profile; squares – RVs, obtained from the two Nasmyth spectra and the He I λ 6678 Å line; triangles – RVs estimations from [7, 8] open triangle – ommited observation [8]

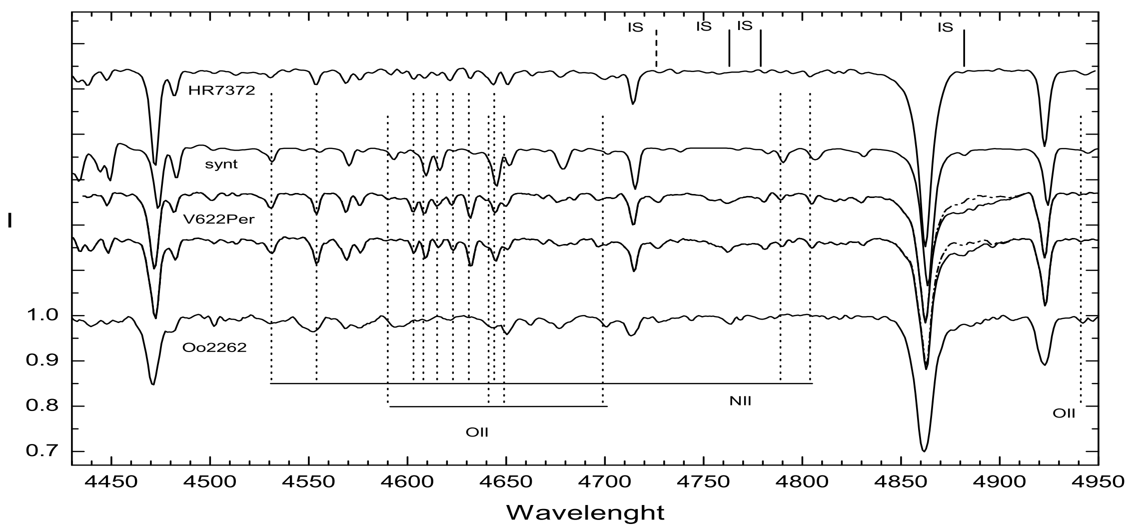

Figure 4: Medium resolution spectra of V622 Per, obtained in the spectral region 4420-4960 Å together with the spectra of two comparison stars HR6787 from list in [9] and member of χ Per cluster Oo2262. The calculated synthetic spectrum is also shown. Positions of stellar spectral lines with estimated abundances is present together with interstellar lines (IS). The dashed lines in the region of the blue wing of the Hβ line are removed interstellar band.

Physical parameters and chemical composition of the components

We also used BV photometry data from [10] to perform light curve analysis. According to calculation by Yakut (private communication) V622 Per is an ellipsoidal double system, with colder primary component (T_1= 21000K) and hotter secondary (T_2= 24000K). Inclination angle of the system i = $43^\circ.7 \pm 2^\circ.9$ was found by Yakut.

Radial velocities and photometrical variability due to ellipsoidality of the components allowed us to obtain most of the main physical parameters of the double system with exception of the radius of the components. The next step of our analysis was to constrain a model of atmosphere of the components with the goal to estimate chemical composition at least of more luminous star.

The temperature T_{eff} of the components were found from the light curve analysis. Next pair of parameters $log\,g_1$ and $log\,g_2$ of the components can be found from the equivalent width of the Hβ line, but only in assumption that gravity one of the components is taken elsewhere. We had to accept that the less luminous component is still an undeveloped star whose position on H-R diagram is close to the main sequence with $log\,g = 4.0$. Then, using luminosity ratio of the components 4:1 and photometry index [c1] and β (took from [2] and [3]), we found that observed EW of the Hβ line had satisfied approximation with $log\,g_1 = 3.0 \pm 0.5$.

The last step of our analyses was the determination of the abundances of the elements of CNO cycle. We used the LTE line blanketing model from [6] for solar abundances with the line formation problem solved by [12] in the program SyntV for finding the basic parameters of the atmosphere of the cool component of V622 Per and estimation of the chemical composition.

The synthetic spectra were calculate with the parameters of atmosphere each of the component taken from our data (T_1 = 21000K, $log\,g_1$= 3.0, T_2 = 24000K $log\,g_2$= 4.0, $V sin\,i$= 60 km s^{-1}, V_{turb}= 10 km s^{-1}). From analysis of synthetic spectrum we have found that CNO abundances of V622 Per are far from solar. Nitrogen lines demonstrate overabundance in comparing to the normal solar abundance. Oxygen abundance is noticeable lower to solar. And even on height-resolution spectra in the Hα region we can not see presence of the C II doublet at the λ6578 Å and λ6582 Å. The deficiency of carbon is presented in the atmosphere of the both of components and should be at least 2-3 dex.

Quality of our data allowed us to obtain only estimations of chemical composition. Abundance of helium He/H is 0.18, excess of nitrogen is $\sim$ 0.5 dex and deficiency of oxygen are about 1 dex in comparison to solar abundances.

The chemical composition of V622 Per is near similar with the composition of β Lyr - well know massive interacting binary with P_{orb}= 12.9 days. In work [1] obtained large He enrichment, extreme nitrogen over-abundant and very underabundant oxygen and carbon. Carbon lines, the same as in the case of V622 Per, were not found in the atmosphere of the primary component.

Conclusions

Relatively short orbital period after active mass exchange in V622Per allow us to conclude that it is type a massive interacting binary with the masses of the component M_1= 9.0M$_\odot$ and M_2= 12.8M$_\odot$. The less massive evolved primary leave main sequence and it is on the way to the red giants stars.

Thereby we have researched massive binary system V622 Per with well know age at 14 million year, V = 9.25, period 5.213^d. We found temperature angular momentum, gravity, masses and estimated the chemical composition of the first component.

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